SOULTION TO CONSTRAINED ECONOMIC LOAD DISPATCH

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SOLUTION TO CONSTRAINED ECONOMIC LOAD DISPATCH

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

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CERTIFICATE

This is to certify that the thesis entitled "**Solution To Constrained Economic Load Dispatch**", submitted by **Sandeep Behera (Roll. No. 109EE0257)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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Sandeep Behera

B.Tech (Electrical Engineering)

<u>Dedicated to</u>

My Parents

ABSTRACT

The power system in modern world has grown in complexity of interconnection and power demands. The focus has now shifted to enhancing performance, increasing customer focus, lowering cost, reliability and clean power. In this changed modern word where we face scarcity of energy, with an ever increasing cost of power generation, environmental concerns necessitate some sort of optimum economic dispatch. Particle Swarm Optimization (PSO) is used to allot active power among the generating stations which satisfy the system constraints and thereby minimizes the cost of power generated. The feasibility of this method is analysed for its accuracy and its rate of convergence. The economic load dispatch problem is carried for three and six unit systems using PSO and conventional lagrange method for both cases i.e. neglecting and including transmission line losses. The results of PSO method was compared with that of conventional method and was found to be superior. The convergence characteristics in PSO method were also found both for loss included and loss neglected case. The conventional optimization methods are unable to solve many complex problems due to convergence of local optimum solution. Particle Swarm Optimization (PSO) since its initiation during the last 15 years, has been a great solution to the practical constrained economic load dispatch (ELD) problems. The optimization technique is evolving constantly to provide better and fast results.

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CHAPTER **1**

Introduction

1.1 INTRODUCTION

Due to large interconnection of the electrical networks, energy crisis in the world and continuous rising prices, it is now very essential to reduce the running costs in electric energy. A saving in the operation in power systems will bring about a major reduction in the operating cost as well as in the quantity of consumed fuel. The main aim of modern electrical power utility is to provide high quality and reliable power supply to the consumers at lowest possible cost and also operating in such a way so that it meets the constraints imposed on the generating units and considers environmental constraints. These constraints give rise to economic load dispatch (ELD) problem to find the optimal combination of the output power of all the online generating units that will minimize the total fuel cost and satisfy the set of inequality constraints and equality constraint. Traditional algorithms such as lambda iteration method, base point participation factor method, Newton Raphson method and gradient method can solve this ELD problems effectively iff the fuel-cost curves of all the generating units are piecewise linear and increasing monotonically. Practically, the input-output characteristics of any generating unit is highly non-linear, non-smooth and also discrete in nature owing to prohibited operating zones, ramp rate limit and multi-fuel effect. Thus, the resultant ELD becomes a very challenging and non-convex optimization problem, which is very difficult to solve using traditional methods. Other methods like dynamic programming, genetic algorithm, artificial intelligence, evolutionary programming and particle swarm optimization (PSO) can solve non-convex optimization problems very effectively and often achieve a faster and near global optimum solution.

1.2 OVERVIEW OF PROPOSED WORKDONE

Many a literature are used to carry out the project. Various references have been taken in this regard. Reference [1] gives a basic insight into the present power system and problem being faced by the modern power system. Reference [2] exclusively deals with the PSO method aof optimization of an economic load dispatch problem. Reference [3] gives an insight into the different cost functions used for optimization of an ELD problem. Reference [4] tells about the recent advances in economic load dispatch such as particle swarm optimization, evolutionary programming, and genetic algorithm and Lagrange method. Reference [5] takes into consideration transmission losses for a problem. Reference [6] gives us the PSOt, a toolbox used for solving the practical problems using PSO. References [7]-[8] gives the advantages and disadvantages of PSO to solve economic load dispatch problem.

1.3 THESIS OBJECTIVES

The following aims are hoped to be achieved at the end of this project:

1) To study the thermal power plant and how it functions.
2) To study the operating cost of a thermal power plant and its various constraints.
3) To formulate optimum load dispatch problem and the cost function.
4) To understand lambda iteration method and Particle Swarm Optimisation method.
5) To compare between the two methods and find out which method is more suitable for any given load dispatch problem.

1.4 ORGANISATION OF THESIS

The thesis is organised into six chapters including the chapter of introduction. Each chapter is different from the other and is described along with the necessary theory required to comprehend it.

Chapter2 deals with the background and basic literature review required before going through the actual thesis. A practical thermal power plant is taken into consideration and each process is analysed. The cost function is studied along with the input output characteristics. Different system constraints are taken into consideration such as equality and inequality constraints. The theory behind lambda iteration method and Particle Swarm Optimisation methods are also studied and analysed.

Chapter3 describes the methodology behind the two different processes. First of all the objective function is written and then its constraints are formulated. Solution process is found out for langrage method and PSO method both for loss neglected and loss neglected case. Flowchart is used wherever necessary.

Chapter4 shows the simulation and results for a practical power system. Two case study are considered. In the first case a three bus system is taken and solution is found using both the processes for loss neglected and loss included case. In the second case study, a six bus system is taken and the whole processes is repeated. Reliability study, comparison tables and convergence characteristics are also studied.

Chapter5 concludes the work performed so far. It also provides an insight into the future study that can be done on this subject.

CHAPTER 2

Background and Literature Review

2.1 THERMAL POWER PLANT

A power plant whose prime-mover is driven by steam is a thermal power plant. Here water is the working fluid. It is heated in the boiler and then circulated with enormous energy to be expanded near the steam turbine to give mechanical work to the rotor shaft of the generator. After steam passes through the turbine, it is condensed and then pumped out to back feed the boiler where it is heated up again.

For simplification purpose, thermal power plants can be modelled as transfer function of energy conversion from fossil fuel into electricity shown in below Fig

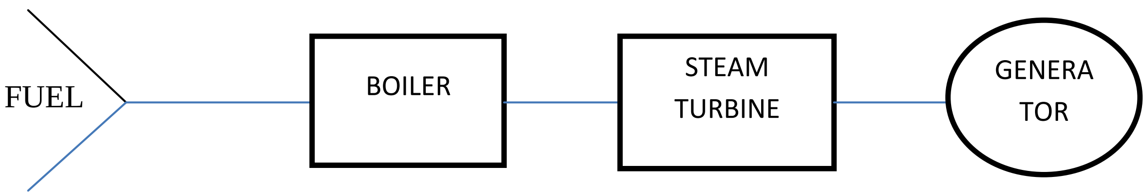


Fig 2.1 Energy conversion diagram of a thermal power plant.

The thermal unit system consists generally of a boiler, a steam turbine and a generator. The input of the boiler is fuel and the output is volume of steam. The relationship between the input and output can be expressed as a complex convex curve .The input of the combined turbine-generator unit is the volume of steam and the output is the electrical power, the overall input-output characteristics in this case can be obtained by combining directly both the input-output characteristics of the boiler and the turbine-generator unit. It is found to be a convex curve.

2.2 OPERATING COST OF A THERMAL POWER PLANT

The factors that influence power generation are the operating efficiency of the generators, fuel cost and transmission line losses. The total cost of generation of power is a function of the individual generation cost of the sources which takes value within some specified constraints. The problem now is to determine the generations of different plants such that the total operating cost is kept minimum. The input to thermal power plant is generally measured in terms of BTU/hr and output power is the active power MW. An input-output curve of a thermal unit is known as the heat-rate curve.

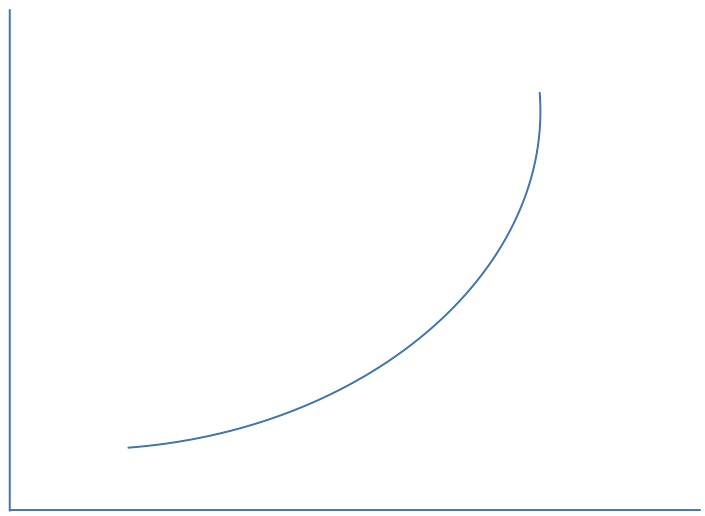


Fig 2.2 Input Output characteristics of a generator unit

For all practical cases, the fuel cost of any generator unit i can be represented as a quadratic function of the real power generations.

$$C_i = A_i * P_i^2 + B_i * P_i + C_i \qquad [1]$$

Therefore, the incremental fuel-cost curve is a measure of how costly it will be to produce the next increment of power generated.

$$dC_i/dP_i = 2A_i * P_i + B_i \qquad [2]$$

2.3 CALCULATION OF INPUT-OUTPUT CHARACTERISTICS PARAMETER

The input-output characteristics of any generating unit can be determined by the following methods.

1. Based on the experiments on the generating unit efficiency.

2. Based on the historic records of the generating unit operations.

3. Based on the design data of the generating unit provided by the manufacturer.

For a practical power system, we can easily obtain the fuel statistics data and power output statistics data. By analysing and computing the data set (F_k, P_k), we can easily determine the shape of the input-output characteristics and hence the corresponding parameters.

2.4 SYSTEM CONSTRAINTS

Generally there are two types of constraints or restrictions, namely

i) Equality constraints

ii) Inequality constraints

2.4.1 EQUALITY CONSTRAINTS

The equality constraint represents the basic load flow equation involving active and reactive power.

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \qquad [3]$$

2.4.2 INEQUALITY CONSTRAINTS

i) Generator Constraints

The KVA loading of a generator can be represented as $\sqrt{P^2 + Q^2}$. The KVA loading should not exceed a pre-specified value in order to have a limit on maximum temperature rise. The maximum active power that is generated from a source is limited by thermal considerations to keep the temperature rise within allowable limits. The minimum power generated by the system is limited by the flame instability of the boiler of the plant. If the power generated in generator falls below a pre-specified level called P_{min}, the unit is not put on the bus bar, therefore we have

$$P_{min} \leq P \leq P_{max} \qquad [4]$$

The maximum value of reactive power is limited by the overheating of rotor and minimum value of reactive power is limited by the stability limit of the machine. Hence, the generator reactive power, Q should not be outside the range of stable operation.

$$Q_{min} \leq Q \leq Q_{max} \qquad [5]$$

ii) Voltage Constraints

The voltage magnitudes and phase angles at various nodes should lie within certain values. The normal operating angle for transmission should lie between 30 to 45 degrees for transient stability reason. A higher operating angle will reduce the stability during faults and lower phase angle assures a proper utilization of the available transmission capacity.

iii) Running Spare Capacity Constraint

These constraints are essential when we have to meet

a) A forced outage of one or more alternators within the system

b) An unexpected load which may be applied on the system.

The total power generation should be such that it should meet load demand, various losses and minimum spare capacity, i.e. $G \geq P_p + P_{so}$

Here G is the total generation, P_{so} is some pre-specified power. A well planned system must have a very less value of P_{so}.

iv) Transmission Line Constraints

The flow of active power and reactive power in the transmission line is limited by the thermal capability of the circuit generally expressed as

$C_p \leq C_{pmax}$; C_{pmax} is the maximum loading capacity of the P^{th} line.

v) Transformer tap settings:

For an auto-transformer, the minimum tap settings is zero and maximum can be 1, i.e. $0 \leq t \leq 1.0$

Similarly, in case of a two winding transformer, if there are tappings on the secondary side, we have

$0 \leq t \leq n$; n is known as the transformation ratio.

vi) Network Security Constraints

If, initially the system is operating satisfactorily and thereafter there is an outage, it could be scheduled or forced one; then it is natural that some of the constraints of the system may be violated. The complexity of those constraints (number of constraints) is increased when a large system is being considered. For this, a study is made with outage of one branch at a time and then more than one branches at a time. The nature of these constraints are same as voltage and transmission line constraints.

2.5 OPTIMUM LOAD DISPATCH

Optimum load dispatch problem involves the involvement of two different problems. The first of these is a unit commitment or a pre-dispatch problem wherein it is required to select optimally out of the available generating sources, to meet the expected load and to provide a specified margin of operating reserve over a specific period of time .The second aspect of economic dispatch problem is the on-line economic dispatch wherein it is required to distribute the load among the generating units connected to the system in such a way so that it minimizes the total cost of operation.

2.6 COST FUNCTION

Let C_i represents the cost in Rs per hour to produce energy in the i^{th} generator. Therefore $C = \sum_{i=1}^{N} C_i$ Rs/hrs. The generated real power, P_{Gi} has an influence on the cost function. To increase the real power generation we have to increase the prime mover torque which in turn requires an increased expenditure on fuel. The reactive power generations, Q_{Gi} does not have any significant influence on Ci because they are controlled by controlling the field excitation. The individual production cost, Ci of generator units is for all practical purposes considered only a function of P_{Gi} , and for the overall production cost C, we thus have :

$$C = \sum_{i=1}^{N} C_i (P_{Gi}) \qquad [6]$$

2.7 LAMBDA ITERATION METHOD

In Lambda iteration(lagrange) method, lambda is the variable introduced to solve the constrained optimization problem and is called the Lagrange multiplier. Value of lambda can be solved by hand by solving a systems of equation. Since all the inequality constraints must be satisfied in each trial hence these equations are solved using the iterative method.

i. First, assume a suitable value of $\lambda(0)$. This value must be more than the largest intercept of the incremental cost characteristics of the various generators.

ii. Now compute the individual generations.

iii. Check for the equality.

$$P_D = \sum_{p=1}^{n} P_N \qquad [7]$$

iv. If not, make a second guess of λ and repeat the above steps.

2.8 PARTICLE SWARM OPTIMIZATION

PSO method simulates the behaviour of bird flocking. Suppose, we are having the following scenario: a group of birds are searching for food in an area randomly. There is only one piece of food in the area that is searched. None of the birds know the location of the food. But they all know how far the food is, after each iteration. Now what can be the best strategy to find the food? The effective one will be to follow the bird which is nearest to the food. PSO learned from this scenario and used this method to solve the optimization problems. In PSO method, every single solution is a "bird" in the search space known as a "particle". All the particles have different fitness values, which can be evaluated by the fitness functions to be optimized, and have certain velocities, which direct the flying of the particles in a direction. The particles fly in the problem space by following the current optimum particles. PSO is initialized by some random particles called solutions and then it automatically searches for the optimum by updating its generations. After each iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far.

This value is called pbest. Another "best" value is the global best value, obtained so far by any particle within the population. This best value is known as global best or gbest. When a particle takes part in the population as its topological neighbours, the best value achieved is a local best and is called pbest. After finding the two best values, particle updates its velocity and positions according to the equations [8] and [9].

$$V_i^{(u+1)} = w * V_i^{(u)} + C_1 * \text{rand}(\,) * (pbest_i - P_i(u)) + C_2 * \text{rand}(\,) * (gbest_i - P_i(u)) \quad [8]$$

$$P_i(u+1) = P_i(u) + V_i(u+1) \quad [9]$$

The term rand rand ( )*(pbest$_i$ -P$_i$(u) is called particle memory influence,

The term rand ( )*(gbest$_i$ -P$_i$(u)) is called swarm influence.

$V_i^{(u)}$ is the velocity of ith particle at iteration ‘u’ must lie within the range

$$V_{min} \le V_i^{(u)} \le V_{max} \quad [10]$$

- A certain parameter called V_{max} determines the resolution or fitness values at which regions are to be searched between the present position and the target position.
- If V_{max} is too high, then particles may fly past good solutions. If V_{min} is too small, then particles may not explore sufficiently beyond local solutions.
- First hand experiences with PSO, Vmax was always set at 10-20% of the dynamic range for every dimension.
- The constants C1and C2 try to pull each particle towards pbest and gbest positions.
- Low values of acceleration constant allow particles to roam far from the target regions before being brought back. On the other hand, high values always result in abrupt movements which may be towards or directed past target regions.

- The acceleration constants C1 and C2 are often set to 2.0 according to past experiences.
- Suitable selection of inertia weight 'ω' is used to provide a balance between global and local explorations, which requires less iterations, on an average, to find a sufficiently optimal solutions.
- In general, the inertia weight *w* is set according to the following equation,

$$W = W_{\max} - \left[\frac{W_{\max} - W_{\min}}{ITER_{\max}} \right] * ITER \qquad [11]$$

Where,

W: inertia weighting factor

W_{max}: maximum value of weighting factor

W_{min}: minimum value of weighting factor

$ITER_{max}$: maximum number of iterations

ITER: current number of iterations

CHAPTER **3**

Methodology

3.1 PROBLEM FORMULATION

The main objective of the economic load dispatch problem is to minimize total fuel cost.

Min $F_T = \sum_{n=1}^{N} Fn$ [12]

Subject to $P_D + P_L = \sum_{n=1}^{N} Pn$ [13]

3.2 ECONOMIC LOAD DISPATCH NEGLECTING LOSSES

LAGRANGIAN MULTIPLIER (LAMBDA-ITERATION) METHOD

$$F = F_T + \lambda(P_D - \sum_{n=1}^{N} Pn\ )$$ [14]

Where λ is the Lagrangian Multiplier.

The derivative of F with respect to the generation P_n and equating it to zero will give the condition for optimum operation of the system.

$$\partial F / \partial P_n = \partial F_T / \partial P_n + \lambda(0-1) = 0$$

$$= \partial F_T / \partial P_n - \lambda = 0$$ [15]

Since $F_T = F_1 + F_2 \ldots\ldots\ldots.. + F_N$

$$\partial F_T / \partial P_n = dF_n / dP_n = \lambda$$ [16]

Therefore, the condition required for optimum operation is

$dF_1/dP_1 = dF_2/dP_2 = \ldots\ldots\ldots\ldots = dF_n/dP_n$ [17]

The incremental production cost of a plant is represented by

$dF_n/dP_n = F_{nn}P_n + f_n$ [18]

F_{nn} represents slope of incremental cost curve

$f_n$is the intercept of incremental cost curve

The active power generation constraints are taken into account while solving these equations. If these constraints are violated for any generator then it is limited to the corresponding limit and the rest of the load is distributed among the remaining generator units according to the equal incremental cost of production.

3.3 ELD WITH LOSS

Optimum load dispatch problem including transmission losses is represented by:

$\text{Min } F_T = \sum_{n=1}^{N} Fn$ [19]

Subject to $P_D + P_L - \sum_{n=1}^{N} Pn$ [20]

Where, P_L is total system loss which is assumed to be a function of generation.

Making use of the Lagrangian multiplier λ, the auxiliary function can be written as

$F = F_T + \lambda\ (P_D + P_L - \sum_{n=1}^{N} Pn)$ [21]

The partial differentiation of this expression when equated to zero gives the condition for optimal load dispatch, or

$$\partial F / \partial P_n = \partial F_T + \lambda(\partial P_L / \partial P_n - 1)$$

$dF/dP_n + \lambda * \partial P_L / \partial P_n = \lambda$ [22]

Here the term $\partial P_L / \partial P_n$ is also known as the incremental transmission loss at plant n and λ is known as the incremental cost of received power generally in Rs. per MWhr. The above equation is a set of n equations with (n+1) unknowns, i.e. 'n' generations are unknown and λ is unknown. These equations are also known as the coordination equations because they coordinate the incremental transmission loss with the incremental cost of production.

To solve these equations loss formula is expressed in terms of generation in this way

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \qquad [23]$$

Where P_m and P_n are the source loadings, B_{mn} is the transmission loss coefficient.

$$\partial P_L / \partial P_N = 2\sum_m B_{mn} P_m \qquad [24]$$

Also $dF_n/dP_n = F_{nn}P_n + f_n$

∴ The coordination equation can therefore be written as

$$F_{mn} P_n + f_n + \lambda \sum 2B_{mn} P_m = \lambda \qquad [25]$$

Solving for P_n we get

$$P_n = (1 - f_n/\lambda * \sum_{m!=n} 2B_{mn} P_m) / (F_n/\lambda + 2B_{nn}) \qquad [26]$$

When transmission losses are included and coordinated, the following points are to be kept in mind for economic load dispatch problem:

1. Whereas incremental transmission cost of production of a plant is always taken positive, the incremental transmission losses can be both positive or negative.

2. The individual generators will always operate at different incremental costs of production.

3. The generation with highest positive incremental transmission loss will operate at lowest incremental cost of production.

3.4 PSO METHOD

1. First, initialize the Fitness Function that is the total cost function from the individual cost functions of the various generating stations.

2. Initialize the PSO parameters, ie, Population size(n) , C1, C2, W_{MAX}, W_{MIN} and error gradient.

3. Input the Fuel cost Functions, MW limits of the generating stations and the B-coefficient matrix and the total power demand.

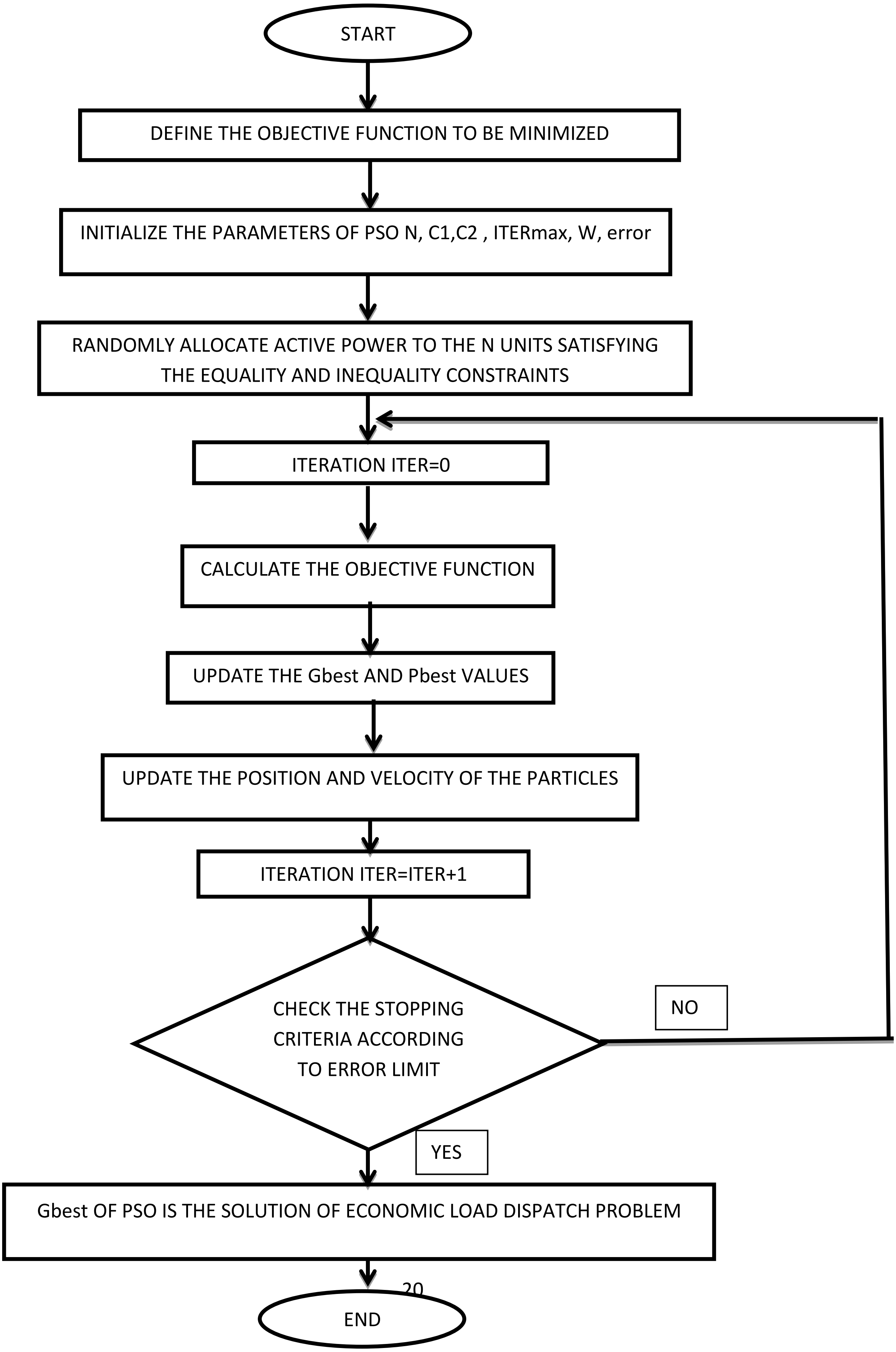
4. At the first step of the execution of the program a large no (equal to the population size) of vectors of active power satisfying the MW limits are randomly allocated.

5. For each value of active power, the fitness function is calculated. All values obtained in an iteration are compared to obtain the Pbest. At each iteration, all values of the whole population till then are compared to obtain the Gbest. At each and every step, these values are updated.

6. At each step, the error gradient is checked and the value of Gbest is plotted till it comes within the pre-specified range.

7. This final value of Gbest is the minimum cost and the active power vector represents the economic load dispatch solution.

3.5 FLOWCHART OF PSO



CHAPTER **4**

Results

The different methods discussed earlier are applied to two cases to find out the minimum cost for any demand problem. One is three generating units and the other is six generating units. Results of Particle Swarm Optimization (PSO) are compared with the conventional lambda iteration method. For the first case transmission line losses are neglected and then transmission line losses are considered. All these simulation are done on MATLAB 2010 environment.

4.1 CASE STUDY -1: THREE UNIT SYSTEM

The cost function characteristics of the three units are given as:

$F1 = 0.00165P_1^2 + 7.97\ P_1 + 555$ Rs/Hr

$F2 = 0.00183P_2^2 + 7.74\ P_2 + 315$ Rs/Hr

$F3 = 0.00467P_3^2 + 7.92\ P_3 + 79$ Rs/Hr [27]

According to the constraints considered in this work among inequality constraints only active power constraints will be considered. There operating limits for maximum and minimum power are also different for each generator. The unit operating ranges are:

$800\ MW \le P1 \le 700\ MW$

$100\ MW \le P2 \le 350\ MW$

$70\ MW \le P3 \le 150\ MW$ [28]

The transmission line loss can be calculated by knowing the loss coefficients. Now the B_{mn} loss coefficient matrix is given by:

B_{mn}=1e-4*[0.750 0.050 0.075

0.050 0.150 0.100

0.075 0.100 0.450] [29]

4.1.1 LAMBDA ITERATION METHOD

In this method, initial value of lambda is guessed in the feasible reason that can be calculated from the derivative of the cost function. For the convergence of the problem, delta lambda should be selected small.

Table 4.1 Lambda iteration method neglecting losses for Three unit system

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3 (MW)	LAMBDA	TOTAL FUEL COST(Rs/hr)
1	500	191.4914	235.4977	73.0109	8.6019	5063.07
2	600	235.8381	275.4825	88.6794	8.7483	5930.58
3	700	280.1848	315.4672	104.3480	8.8946	6812.73
4	800	328.5601	350.0000	121.4399	9.0542	7709.59

Fig 4.1 Cost vs Power Demand Curve for Three unit system neglecting losses

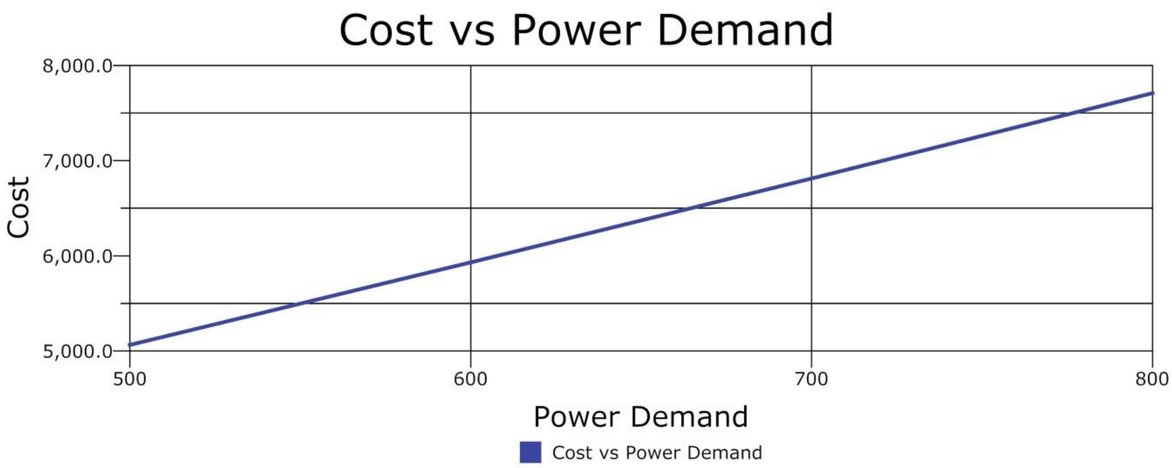


Table 2 shows the economic load dispatch result of the system including transmission line losses. The transmission line losses are calculated with the help of B-Coefficient matrix.

Table 4.2 lambda iteration method including losses for a Three unit system

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3(MW)	PL(MW)	LAMBDA	TOTAL FUEL COST(Rs/hr)
1	500	163.3357	257.8459	78.2517	4.4333	8.7802	5103.14
2	600	206.3849	304.2247	95.4534	6.5130	9.9710	5990.67
3	700	243.7787	350.0000	115.1939	8.9725	9.1239	6897.45
4	800	314.7255	350.0000	148.3722	13.0976	9.4771	7831.89

4.1.2 PSO METHOD

PSO method was also applied to the above system to obtain economic load dispatch of similar load requirements. PSO method was implemented according to the flow chart shown. For each sample load, under the same objective function and individual definition, 20 trials were performed to observe the evolutionary process and to compare their quality of solution, convergence characteristics and their computation efficiency.

PSO METHOD PARAMETERS**:**

POPULATION SIZE: 100

MAXIMUM NO OF ITERATION: 100000

INERTIA WEIGHT FACTOR (w): W_{max}=0.9 & W_{min}=0.4

ACCELERATION CONSTANT: C1=2 & C2=2

ERROR GRADIENT: 1e-06

Table 4.3 PSO method neglecting losses for a three unit system

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3(MW)	TOTAL FUEL COST(Rs/hr)
1	500	168.5706	236.5108	76.9286	5063.186043
2	600	244.8714	267.1067	88.0220	5930.487310
3	700	284.3237	310.0537	105.6226	6812.815542
4	800	325.8915	349.9995	124.1090	7709.639937

Table 4.4 Comparison of results between Lagrange method and PSO method for Three-unit system neglecting losses.

SI.No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	500	5103.14	5063.186043
2	600	5990.67	5930.487310
2	700	6897.45	6812.815542
3	800	7831.89	7709.639937

Table 4.5 PSO method including losses for a three unit system

Sl No.	POWER DEMAND(MW)	P1(MW)	P2(MW)	P3(MW)	TOTAL FUEL COST(Rs/hr)
1	500	168.5569	257.3320	78.5496	5103.135435
2	600	207.1892	303.5058	95.8279	5990.675971
3	700	245.7466	350.0000	113.2681	6897.419144
4	800	317.0792	350.0000	146.0863	7831.852782

Table 4.6 Comparison of results between Conventional method and PSO method for Three-unit system including losses

Sl No.	**Power Demand (MW)**	**Conventional Method (Rs/Hr)**	**PSO Method (Rs/Hr)**
1	500	5103.14	5103.135435
2	600	5990.67	5990.675971
3	700	6897.45	6897.419144
4	800	7831.89	7831.852782

For Power demands of 500 MW, 600 MW, 700 MW, 800 MW neglecting losses the total fuel cost for 20 runs is observed to study the reliability of the solution provided by this method.

Table 4.7 Reliability Evaluation for PSO method.

Sl No.	**Power Demand (MW)**	**Min(MW)**	**Mean(MW)**	**Std Deviation(MW)**
1	500	5821.439522	5063.186043	0.009738967
2	600	5930.478564	5930.487310	0.008745631
3	700	6812.809377	6812.815542	0.006164467
4	800	7709.630697	7709.639937	0.009240757

Fig 4.2 Reliability Evaluation of PSO Method for a Three unit System

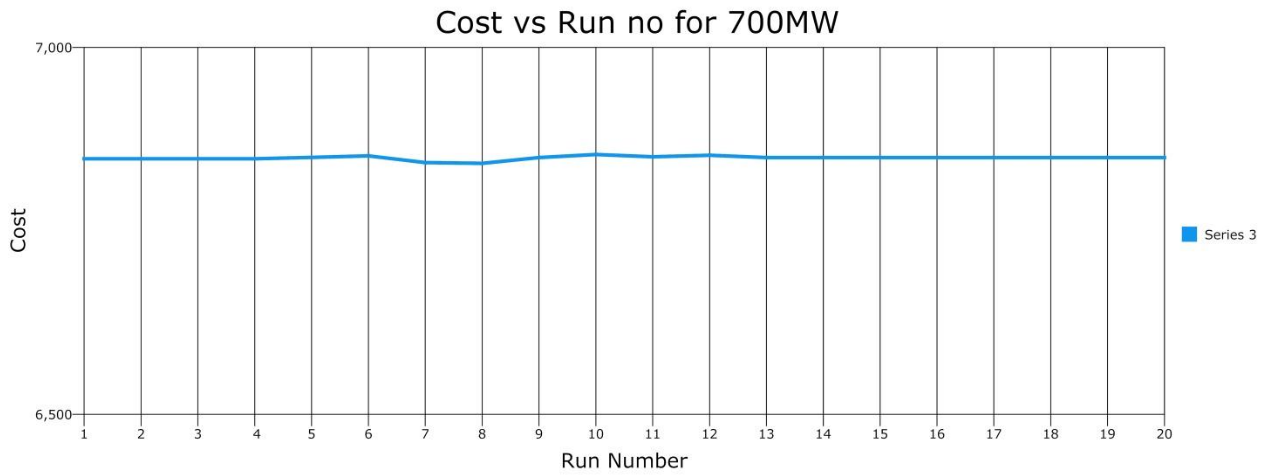


Fig 4.3 Convergence Characteristics of PSO Method for Three unit System(500 MW)

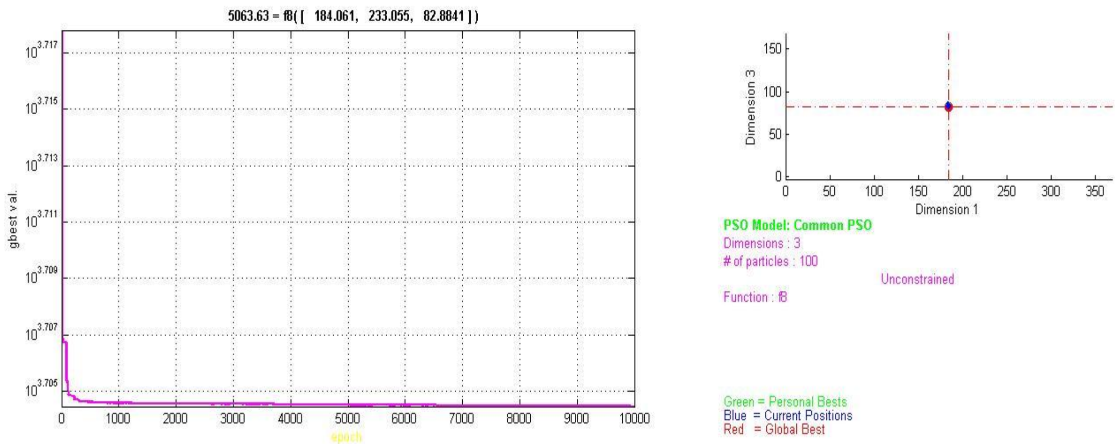


Fig 4.4 Convergence Characteristics of PSO Method for Three unit System(600MW)

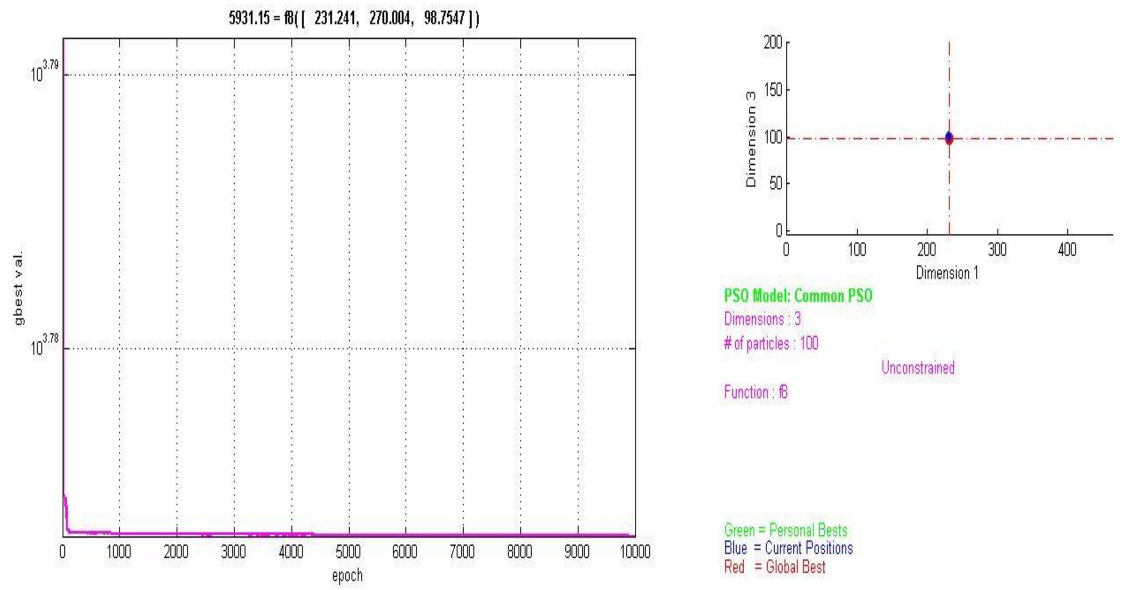


Fig 4.5 Convergence Characteristics of PSO Method for Three unit System(700MW)

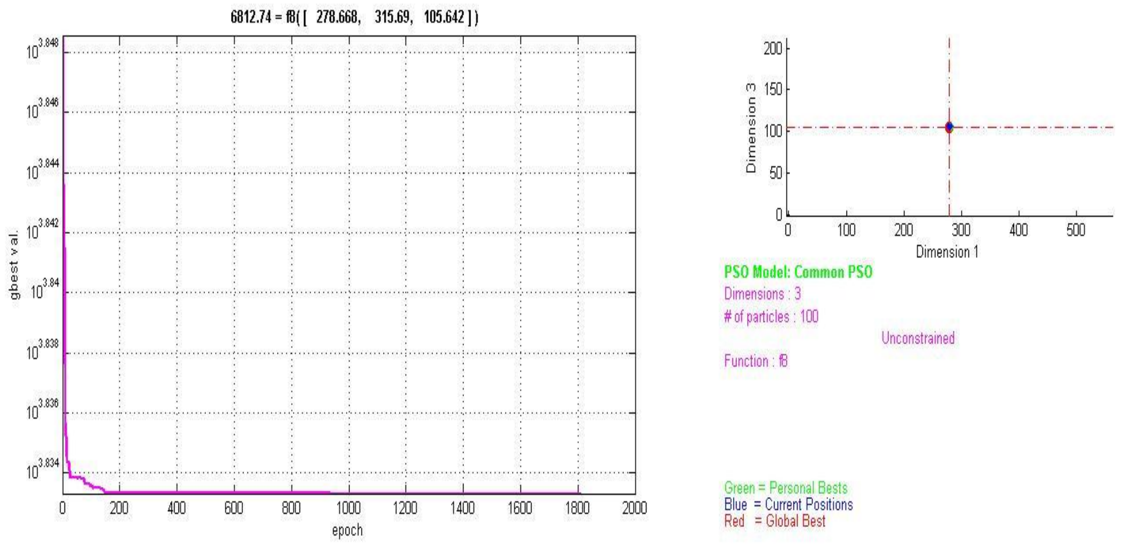
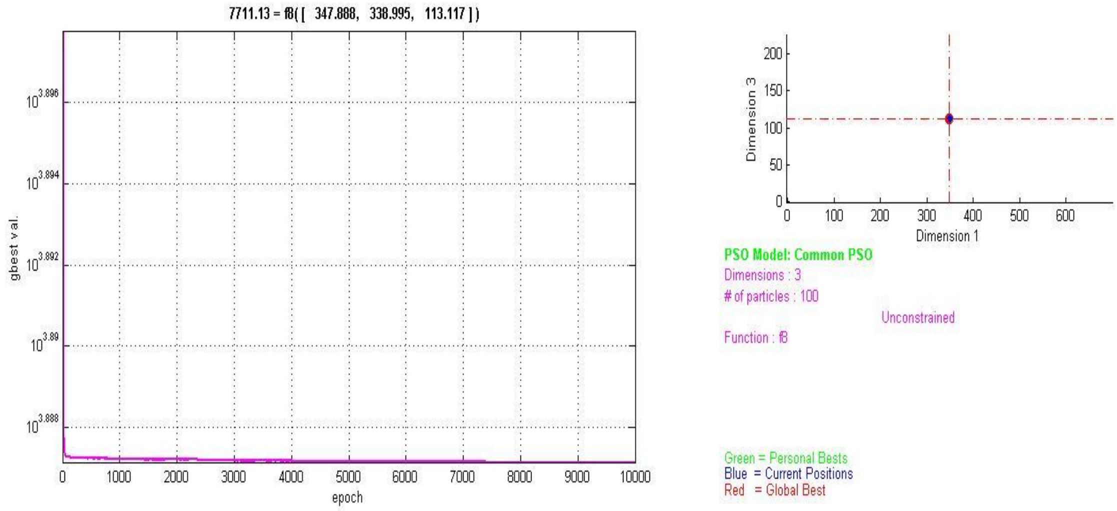


Fig 4.6 Convergence Characteristics of PSO Method for Three unit System(800MW)



4.2 CASE STUDY-2: SIX UNIT SYSTEM

CONVENTIONAL (LAGRANGE MULTIPLIER) METHOD

The cost function characteristics of the three units in Rs/hr are given as:

F_1=0.15240P_1^2+38.53973P_1+756.79886

F_2 = 0.10587P_2^2+ 46.15916P_2 +451.32513

F_3 = 0.02803P_3^2+ 40.39655P_3+1049.9977

F_4 = 0.03546P_4^2+ 38.30553P_4+1243.5311

F_5 = 0.02111P_5^2+ 36.32782P_5+1658.5596

F_6 = 0.01799P_6^2+ 38.27041P_6+1356.6592 [30]

The unit operating constraints are:

10 MW ≤ P1 ≤ 125 MW; 10 MW ≤ P2 ≤ 150 MW;

35 MW ≤ P3 ≤ 225 MW; 35 MW ≤ P4 ≤ 210 MW;

130 MW ≤ P5 ≤ 325 MW; 125 MW ≤ P6 ≤ 315 MW [31]

B-Coefficient Matrix:

B= 1*exp(-5)*

$$\begin{bmatrix} 14.0 & 1.7 & 1.5 & 1.9 & 2.6 & 2.2 \\ 1.7 & 6.0 & 1.3 & 1.6 & 1.5 & 2.0 \\ 1.5 & 1.3 & 6.5 & 1.7 & 2.4 & 1.9 \\ 1.9 & 6.0 & 1.7 & 7.1 & 3.0 & 2.5 \\ 2.6 & 1.5 & 2.4 & 3.0 & 6.9 & 3.2 \\ 2.2 & 2.0 & 1.9 & 2.5 & 3.2 & 8.5 \end{bmatrix}$$ [32]

Table 4.8 Lambda iteration method neglecting loss for a six unit system

SL No.	Power demand	P1	P2	P3	P4	P5	P6	Lambda	Total Fuel Cost
1	700	15.71706	11.0000	53.57180	113.0506	273.8428	232.81762	47.7641	36563.50
2	800	17.896753	11.0000	65.6815	128.5088	310.6158	266.296	49.1696	41410.18
3	900	20.67590	11.0000	81.12183	148.218	330.000	308.9838	50.9616	46406.55
4	1000	36.1001	15.9812	163.1551	158.4531	313.0082	313.3023	49.543026	50363.69
5	1100	43.1896	26.1866	201.7012	188.9226	325	315	51.703919	55414.34

Table 4.9 PSO method neglecting losses for a six unit system

Sl No.	POWER DEMAND (MW)	P1(MW)	P2(MW)	P3(MW)	P4(MW)	P5(MW)	P6(MW)	TOTAL FUEL COST (Rs/hr)
1	800	17.885923	11.0000000	65.7052715	128.4972	310.590703	266.3208	40675.7682
2	900	20.658600	11.000000	81.1736316	148.23803	329.999999	308.92973	46406.54092
3	1000	26.6101397	18.88717957	114.1243199	190.378360	312.9748852	3.19999999	50352.12860

Table 4.10 Lambda iteration method considering transmission loss for a six unit system

SL No.	Power demand	P1	P2	P3	P4	P5	P6	Lambda	Total Fuel Cost	Ploss
1	700	17.92616	11.0000	66.207651	121.88490	273.8128	230.21768	51.0257	37583.43	21.0493
2	800	20.56074	12.088718	80.73266	139.294	311.339	263.593	53.10000	42790.95	27.6092
3	900	36.8636	21.0765	163.9265	153.2239	284.1656	272.7317	52.315997	47045.16	31.9878
4	1000	41.1831	27.7776	186.5561	170.5768	310.8251	302.5631	54.010538	52361.14	39.4818
5	1100	48.1751	36.1684	220.1341	202.4611	325.0000	315.0000	54.813989	57871.60	46.9386

Table 4.11 PSO method including losses for a six unit system

Sl No	Power Demand (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	TOTAL FUEL COST(Rs/hr)
1	800	17.9032190	11.0000000	65.6787340	128.55176	310.527610	266.3386	41410.17317
2	900	20.669389	11.00000	81.212192	148.228011	330.00000	308.890300	46406.54127
3	1100	35.510068	31.02988613	163.4600	220.0000	330.0000	320.0000	50362.77716

Table 4.12 Comparing results between Conventional method and PSO method for SIX-unit system without losses

SI.No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	800	42790.95	40675.7682
2	900	47045.16	46406.54092
2	1100	57871.60	50352.12860

Table 4.13 Comparison of results between Conventional method and PSO method for SIX-unit system including losses

SI.No.	Power Demand (MW)	Conventional Method (Rs/Hr)	PSO Method (Rs/Hr)
1	800	41410.18	41410.17317

2	900	46406.55	46406.54127
3	1000	50363.69	50362.77716

Fig 4.7 Convergence Characteristics of PSO Method for six unit System (800 MW)

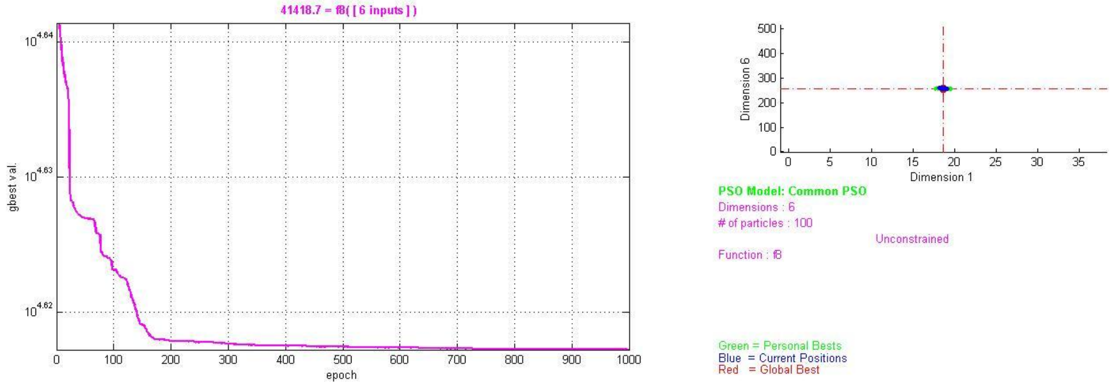


Fig 4.8 Convergence Characteristics of PSO Method for six unit System (900 MW)

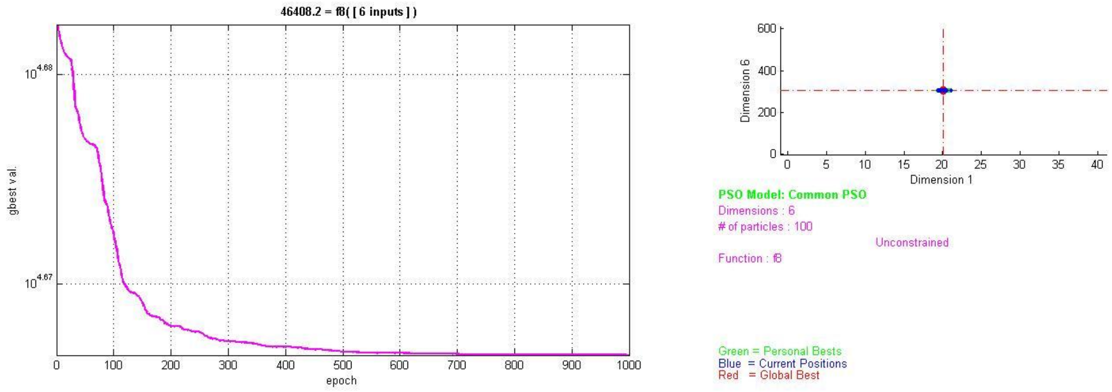
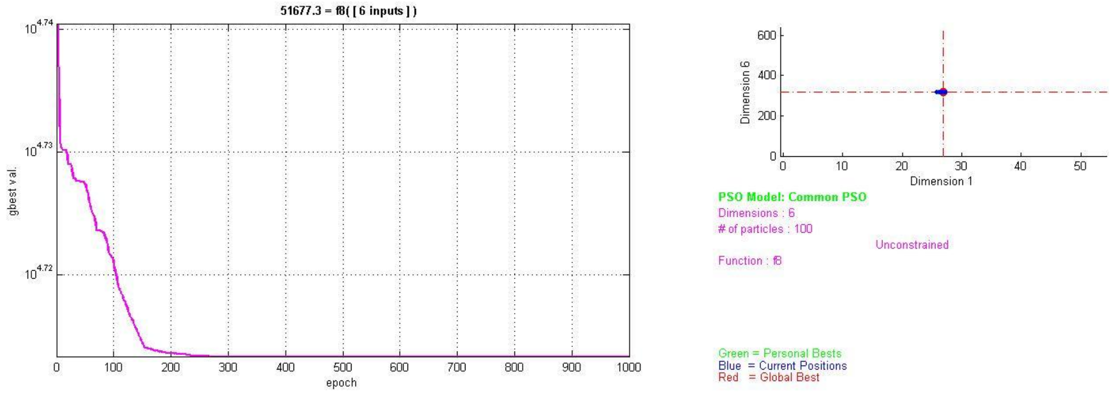


Fig 4.9 Convergence Characteristics of PSO Method for six unit System (1000 MW)



CHAPTER 5

Conclusion and Future Work

5.1 CONCLUSION

Lagrange and PSO method were employed to solve an ELD problem with a three unit system as well as a six unit system. The PSO algorithm showed superior results including high quality solution and stable convergence characteristics. The solution of PSO was close to that of the conventional method but gives better solution in case of higher order systems. The comparison of results for the test cases of three unit system clearly shows that the proposed method is indeed capable of obtaining higher quality solution efficiently for higher degree ELD problems. The convergence characteristics of the proposed algorithm for the three unit system is plotted. The convergence seems to be improving as the system complexity increases. Thus solution for higher order systems can be obtained in much less time than the conventional method. The reliability evaluation of the proposed algorithm for different runs of the program is also pretty good, which shows that irrespective of the no of runs of the program it is capable of obtaining same result for the problem. Many cases of non-linear characteristics of the generators can be handled efficiently by the method. The PSO technique used here uses a inertia weight factor for faster convergence. The inertia weight factor is taken as a dynamically decreasing value from Wmax to Wmin at and beyond ITER max. The convergence characteristics of the methods for varying ITERmax was analyzed. Values of ITERmax between 1000-2000 gave better convergence characteristics, so the value of 1500 is used for optimum results.

5.2 FUTURE WORK

The study of economic load dispatch can be further extended to other processes like genetic algorithm and evolutionary programming. Comparative studies can be performed between all the above methods and their pros and cons studied. Optimum economic load dispatch should be prepared for all the methods along with cost of production of electric power. The most economical solution should be put to practical use in a power system.

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